

The Secret Life of Quartz; SEM-Cathodoluminescence of Quartz grains from Andrill SMS core and recycling of sediments

ANTA604-Supervised Project

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Abstract

Scanning Electron Microscope-Cathodoluminescence combined with optical microscopy has been used to identify recycling in single quartz grains from the Andriill SMS core, from the Victoria Land Basin. Using Bernet & Bassett's classification flow chart (2005) likely source rock types for single detrital quartz grains have been identified. The majority of grains analysed were classified as plutonic, primarily derived from the Granite harbour intrusive granites. Two percent of plutonic grains showed remnant silica cement, which is evidence that the grains were recycled through the Transantarctic Mountains. Less than 1% of grains were identified as metamorphic. They were characterised by a dark, featureless appearance in CL and are derived from the metasedimentary Koettlitz group. Very few volcanic grains were identified. In a wider context, this information can be used to aid the delineation of the Paleoclimate history of Antarctica as sediment transport and delivery are known to vary over time as the climate and tectonics of the region continually evolve.

Table of Contents

ABSTRACT.....	2
TABLE OF CONTENTS	3
INTRODUCTION.....	4
OBJECTIVES.....	5
GEOLOGIC AND PALEOCLIMATE SETTING.....	5
METHOD	7
RESULTS	9
INTERPRETATION.....	14
DISCUSSION.....	15
CONCLUSION	16
REFERENCES	17

Introduction

The provenance of single quartz grains from the Andrill Southern McMurdo Sound (SMS) core in the Victoria Land Basin (VLB) can be used in conjunction with other techniques to identify sediment source rocks in the Transantarctic Mountains. By applying Scanning Electron Microscope Cathodoluminescence (SEM-CL) and optical microscopy techniques to individual quartz grains their history from diagenesis to deposition can be learned.

Of particular interest is the presence of silica cements on well-rounded quartz grains. Since quartz from the Beacon Supergroup is originally derived from basement rocks, these cements, which are only visible in a CL image, are the only evidence that the grains have undergone recycling. In this case, recycling would involve being eroded, transported from their original source and re-deposited before being uplifted with the Transantarctic Mountains. Then they would subsequently be re-eroded and finally deposited offshore in the Victoria Land Basin. Silica cements seen in CL are the only way to differentiate these recycled grains from grains that have been transported straight from a basement source.

The ANDRILL drilling project is a scientific collaboration between New Zealand, USA, Germany and Italy with the aim of delineating the geological and paleoclimatological history of Antarctica, using drill core obtained from the Ross Sea region. Data from projects such as this can be used to piece together the glacial and tectonic history of the region in order to gain a better understanding of the geological and climatological processes that have shaped the landscape over time.

Objectives

This project uses integrated Petrographic and Scanning Electron Microscope Cathodoluminescence (SEM-CL) to determine the provenance of quartz grains present in the SMS drill core. This is a useful technique for quartz rich sediment as different characteristics of a quartz grain can be determined using SEM and optical microscopy together. The SEM provides information on how grains were formed, as opposed to Optical Microscopy, which shows the changes that the grains have undergone during diagenesis and metamorphism. These techniques can be combined to gain an overall idea of the 'type of source' of grains.

This is useful information, as the 'type of source' can then be used to identify the original source of the quartz grains, whether it be the Granite Harbour Intrusives (Plutonic), the metasedimentary Koettlitz group (metamorphic) or volcanic grains from the McMurdo volcanics. There is also a possibility of recycled sedimentary grains derived from the Beacon Supergroup. These grains are plutonic, and are originally sourced from basement rocks, but over time they have been recycled through the Transantarctic Mountains. These recycled grains are identified through the presence of silica cement, which clearly indicates that they have been sourced from the Beacon Supergroup (Bassett & Barnard, 2010).

Geologic and Paleoclimate Setting

The ANDRILL drilling project is a scientific collaboration between New Zealand, USA, Germany and Italy with the aim of delineating the paleoclimate history of Antarctica, using drill core obtained from the Ross Sea region. Samples studied are from the Southern McMurdo Sound core, which was drilled in 2007 from a sea-ice platform situated in Southern McMurdo Sound, approximately 25km from McMurdo station. The rig drilled into

thick sediments on the sea floor, reaching a maximum depth of 1138.54 (Zatin, Talarico, & Sandroni, 2010). The SMS drill hole is situated The Victoria Land Basin (VLB), a 350km long structural half-graben, hinged on its Western side at the Transantarctic Mountain (TAM) Front, and is part of the West Antarctic Rift system. This formed due to crustal extension and subsidence during the Cenozoic. During the Miocene sediments were transported by river and glacier flow from the Transantarctic Mountains, which were rising at the time and had reached about half of their present day height (Faure & Mensing, 2010).

Sediments in the basin are derived from units in the TAM segment facing the VLB. The basement of the Transantarctic Mountains consists of the Proterozoic metasedimentary Koettlitz group, present in the Royal Society Range, Koettlitz Glacier, Ferrar Glacier and the Dry Valleys area (O'Toole, 2010). This is a multiply folded metasedimentary group of varying metamorphic grade (Faure & Mensing, 2010). The Koettlitz group is intruded by the Granite Harbour group, which can be seen in outcrop in the Victoria, Wright and Taylor Valleys. The Granite Harbour group is known to be of Proterozoic-Cambrian age, and can be divided into three main suites (Allibone, Smillie, & Cox, 1991). The top of the basement section is truncated by the Kukri erosion surface, and overlain by the Beacon Supergroup. The Beacon Supergroup can be divided into the Lower, Devonian aged Taylor group, mainly of Granite Harbour and Koettlitz origin (Savage, 2005). The upper section is the younger Victoria Group of Permian-Triassic age (Gilmer, 2008). The Ferrar Dolerite later intruded into the basement and sedimentary cover concurrently with the Kirkpatrick Basalt, forming wide sills. A geological map of the area is shown in Figure 1. The emplacement of Ross Island volcanoes in the late Cenozoic resulted in significant modification of the McMurdo Sound palaeogeography.

Samples studied in this project are from depths of 448.31, 489.89, 528.79, and were selected for the prevalence of large, well rounded quartz grains, necessary to test the hypothesis that well rounded quartz grains may contain silica cements, evidence of sediment recycling.

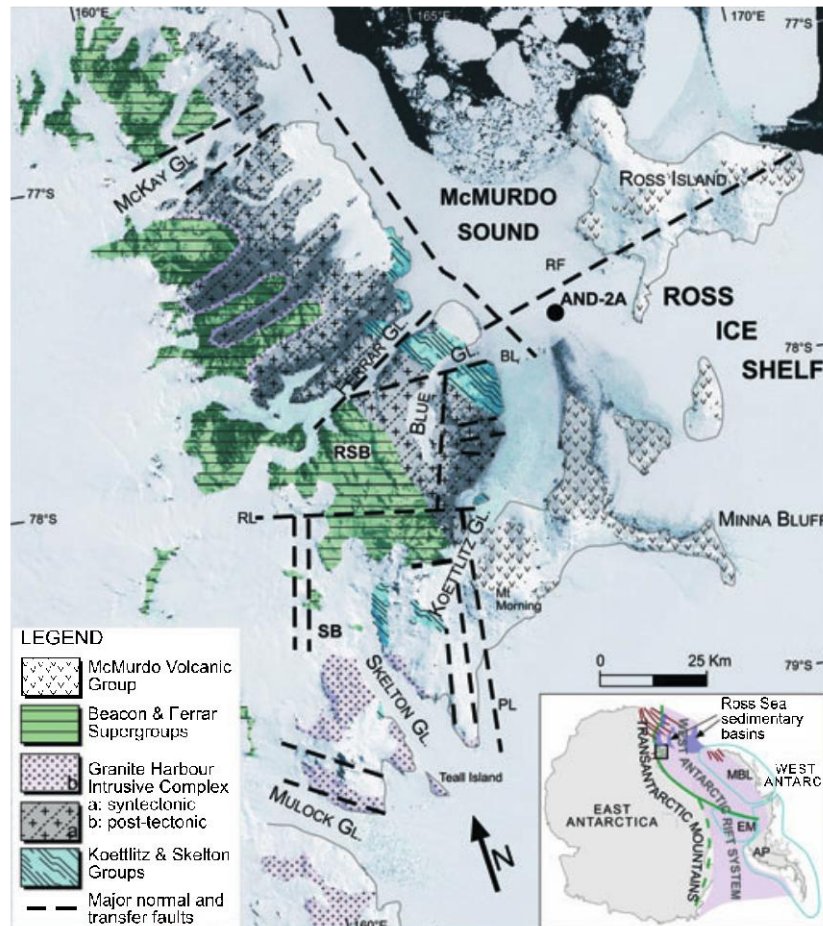


Figure 1 Geological map of the tectonic setting showing the Transantarctic mountains, Victoria Land Basin, source glaciers and the drill hole location (Zatin, Talarico, & Sandroni, 2010)

Method

Analysis by single-quartz-grain SEM-CL/Optical Microscopy was carried out based on the technique detailed by Bernert and Bassett (2005). Using this method the characteristics of quartz grains captured in SEM images can be compared with the characteristics of the same grain as seen under an optical microscope. This is useful as both techniques provide different information about the provenance of the quartz grain.

Slides that contained the highest amount of well-rounded quartz grains were selected for further analysis. On highly polished thin sections, areas that contained the most well rounded grains were marked using a felt tip pen to aid navigation, and carbon coated.

We found that the best balance of image quality and time taken to obtain each image was achieved by using a scanning speed of 320 seconds per image, at a magnification of x75. This meant that we were able to obtain a sufficient number of quality images, capturing the most grains at sufficient resolution, in the limited SEM time available.

Two images were taken of each field of view. First a backscatter electron image was taken using a 'slow fine view freeze'. The addition of this step allows for easy identification of quartz grains, as they appear dark and stand out in the BSE image due to the low atomic number of quartz. A CL image of the same frame is then captured using a scanning speed of 320 seconds per image.

The main features identified using an Optical Microscope were grain shape and extinction. During metamorphism quartz grains undergo deformation, with increasing pressure and temperature they go through a series of stages that constitute a continuum (Young, 1976). Therefore different types of extinction can be indicative of different quartz source types (Basu et. al, 1975). I used four categories for the classification of extinction: Non-undulose, undulose, polycrystalline (<3) and polycrystalline (>3). Non-undulose and undulose grains indicate no or minor deformation, where as polycrystallinity is evidence that grains have been subject to stronger deformation, or have been metamorphosed.

Once sufficient SEM images had been obtained from each slide, a comparison with Optical Microscope images is undertaken, on 100 single quartz grains on each slide, on a gran by grain basis. The results are tabulated, see Table 1. For data collection I used the categories:

Optical Properties

- Rounding: Well Rounded, Sub-Rounded, Sub-Angular, Angular
- Extinction: Non-Undulose, Undulose, Polycrystalline: <3, >3
- Cracks/ No Cracks

CL Properties

- CL Colour: Dark Featureless, Medium Featureless, Light Featureless, Patchy/Mottled
- CL Features: Microcracks; Zoning: Soft Edges, Zoned: Sharp Edges
- Silica Cement

Once I had recorded information from each category I used the flow chart 'Integrated SEM-CL/optical microscopy analysis' from Bernet and Basset (2005) to identify the likely grain type.

Results

Classification of single quartz grains based on SEM-CL and optical microscopy is summarised in Table 1.

The majority of the quartz grains analysed were categorised as plutonic, making up 85% of total grains analysed and the mix of angular and rounded grains was approximately even. Characteristic features of plutonic grains included microcracks, which were seen in 77% of grains. These appeared as thin, light or thicker dark cracks that had a 'spidery' appearance in CL. Some of the plutonic quartz grains (2%) showed dark remnant silica cement at their edge under CL, which is evidence of recycling. The origin of Silica cement is attributed to pressure dissolution where pore solutions become enriched in silica, which is re-precipitated as overgrowths (Tucker, 2001). Quartz grains have undergone this process

as part of the Beacon Super group in the Transantarctic Mountains. CL images of characteristic quartz grains can be seen in Figures 2-5.

Metamorphic grains made up slightly less than 1% of the total analysed. On average metamorphic grains were more angular than plutonic, with 79% being categorised as angular or sub-angular. 64% of the metamorphic grains showed undulose extinction. The rest showed polygonal extinction. This is typical of metamorphic grains (Young, 1979). Metamorphic grains had a higher proportion of 'dark' coloured and 'patchy' CL grains than the Plutonic or Volcanic groups. Typically metamorphic grains were relatively dark and featureless in CL.

Generally volcanic grains were classified as such due to their non-undulose extinction, which was seen in 100% of grains, and their generally featureless appearance. Three quarters of the grains classified as volcanic were rounded as opposed to angular, and all but one showed medium colour CL. As with metamorphic grains, volcanic grains were very nondescript under CL, however Volcanic grains showed medium CL colour, instead of dark. Overall volcanic grains were the smallest group, and the hardest to classify due to their plain appearance

Table 1 Summary table of single quartz grain characteristics

Totals (292)														
Interpretation	Optical Microscope						SEM-CL							
	Rounded	Angular	Extinction			Open Cracks	Microcracks	Cement	Zoning		CL Colour			
			N	U	P				Soft Edges	Sharp edges	Patchy/Mottled	Dark	Medium	Light
Plutonic (256)	131	125	130	111	15	183	218	47	6	12	14	4	158	80
Metamorphic (24)	6	19	0	15	9	20	9	0	0	1	5	7	11	1
Volcanic (12)	9	3	12	0	0	9	0	0	1	0	0	1	11	0
Totals	145	147	142	126	24	212	227	47	7	13	19	12	180	81

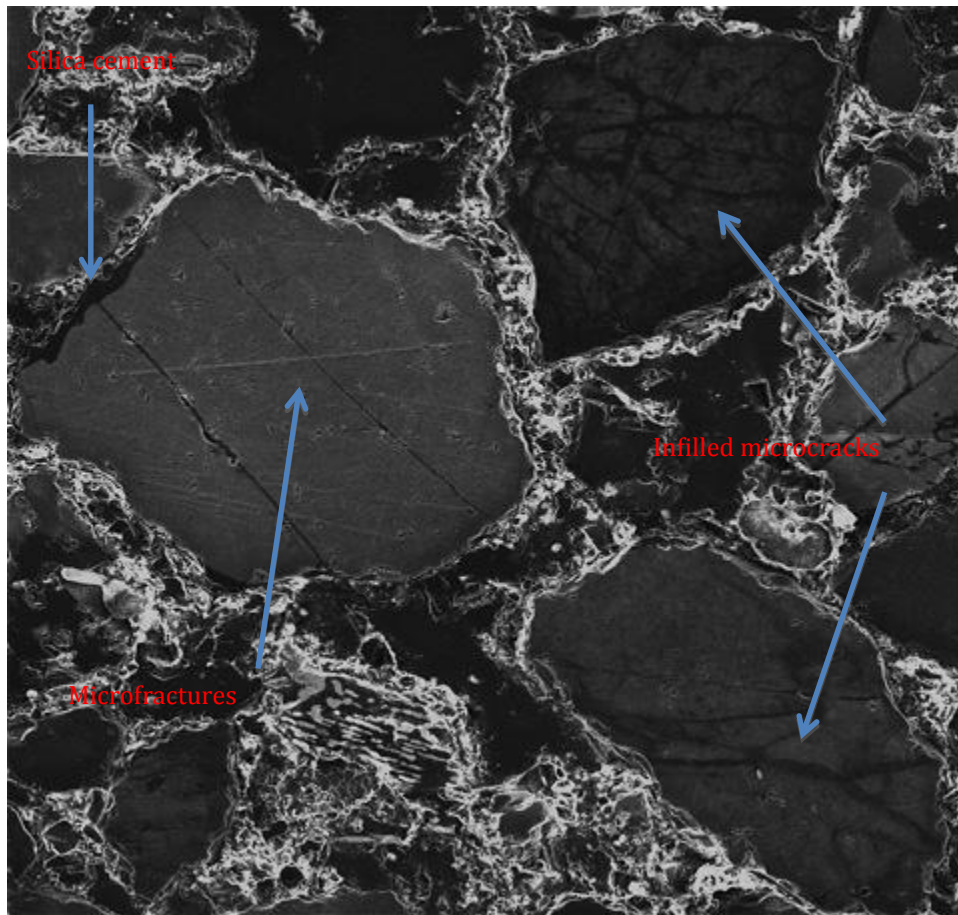


Figure 2 Characteristic plutonic quartz grains under CL

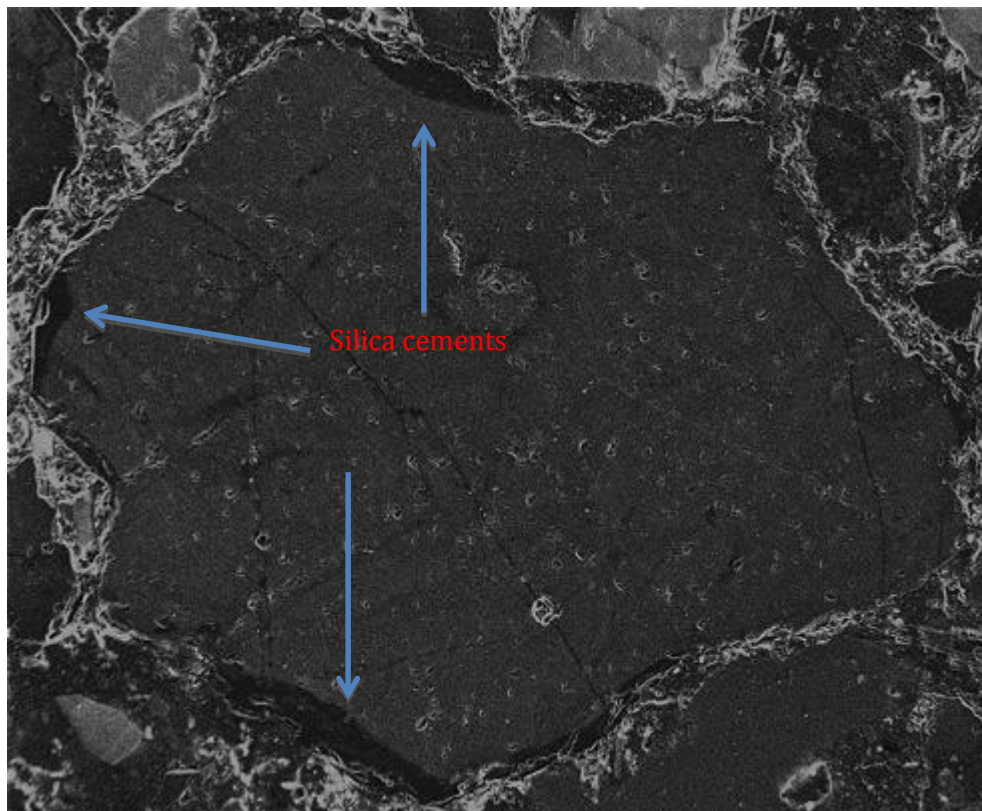


Figure 3 CL image of Single quartz grain showing silica cement at edges

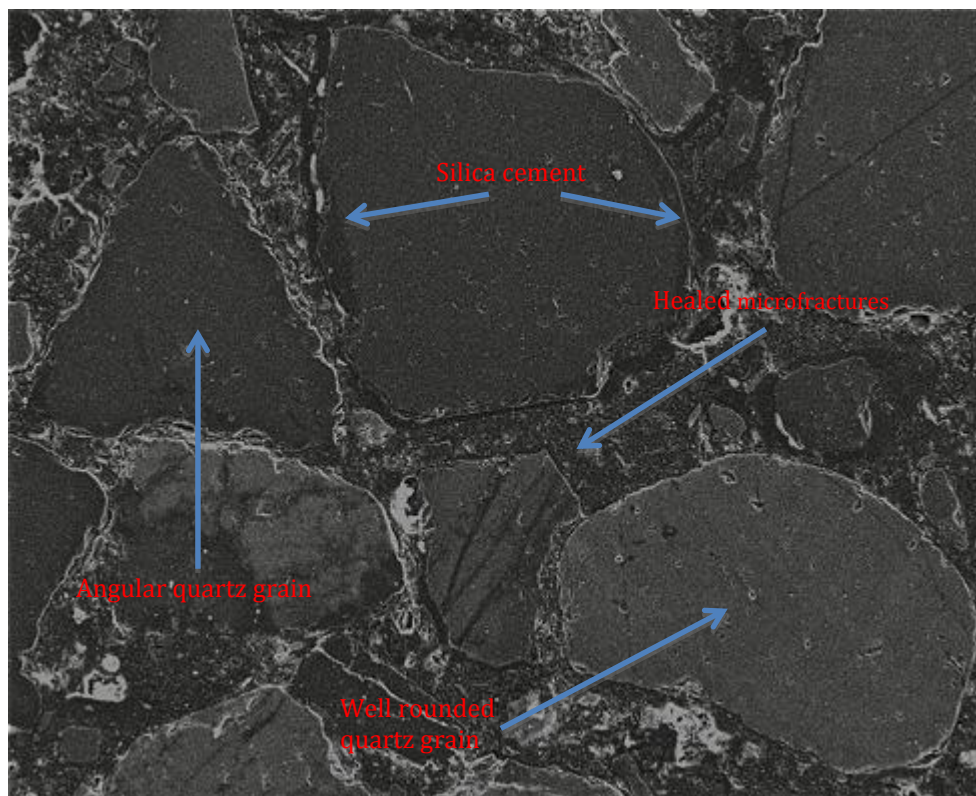


Figure 4 Angular and rounded plutonic quartz grains under CL

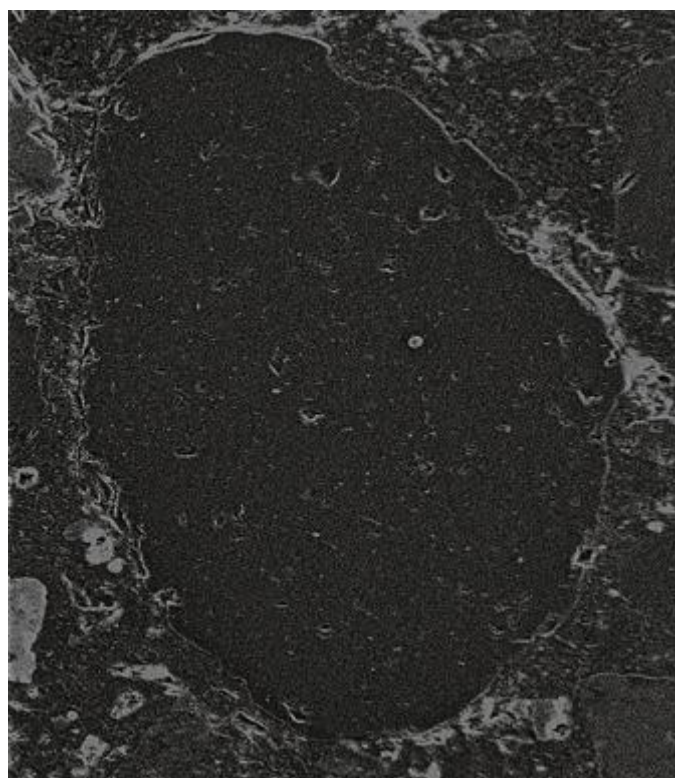


Figure 5 Typical metamorphic quartz grain under CL

Interpretation

Results indicate that quartz grains present in the slides analysed are mainly plutonic, with some metamorphic and volcanic grains also identified. Plutonic quartz grains are derived from the Granite Harbour Intrusive granites, which can be seen in outcrop in the Dry Valleys. Metamorphosed grains are likely to have originated from the metasedimentary Koettlitz group, which outcrops in the Royal Society Range (Faure & Mensing, 2010). Volcanic quartz grains are derived from porphyritic rhyolite clasts, known to be present in conglomerates in the Beacon Supergroup (Savage, 2005).

Some quartz grains show evidence of silica cement, which is indicative of sediment recycling. These grains are derived from the Beacon Supergroup, which originated primarily from the Granite harbour intrusives (Savage, 2005). They have then been uplifted with the Transantarctic Mountains, subsequently re-eroded, and finally deposited offshore in the Victoria Land Basin alongside less well rounded grains, which have been transported directly from source.

As quartz from the Beacon Supergroup is originally derived from basement rocks, identification of these silica cements, which form as overgrowths during pressure dissolution (Tucker, 2001), is the only way to differentiate these recycled grains from grains that have been deposited straight from a basement source. CL imaging is the best way to do this, as the silica cements are often not distinguishable from the original quartz grain under an optical microscope.

Large amounts of glass in some slides also indicate volcanic activity in the area, predominantly from the McMurdo Volcanics of Ross Island. However it is unlikely that these volcanoes were a source of volcanic quartz grains as the Ross Island volcanoes are mainly basaltic. A possible source of the volcanic quartz identified under CL is porphyritic rhyolite clasts, known to be present in conglomerates in the Beacon Supergroup (Savage,

2005). Therefore these clasts may also have originated from the Beacon Supergroup in Transantarctic Mountains, before being deposited in the VLB.

Discussion

Quartz is a particularly useful provenance tool in this case as it can be analysed relatively easily using SEM-CL and optical microscopy to determine the original type of source of quartz grains, and in this case to identify recycling evident through the presence of quartz cements. As silica cements are often not distinguishable from the original quartz grain under an optical microscope, CL provides a relatively cheap and easy way to identify recycling, making this a very useful provenance technique. This combined SEM-CL/optical microscopy technique is currently underutilised; It appears that so far it has only been successfully used to identify silica cements in single quartz grains once before (Bernet, Kapoutsos, & Bassett, 2007)

The identification of volcanic quartz grains proved challenging, when relying solely on the classification flow chart by Bernet & Bassett (2005). Frequently the only flowchart criteria for differentiating between volcanic and plutonic grains was the expected presence of microcracks in plutonic grains. Due to my inexperience with this technique and imperfect CL images, this was not sufficient information to confidently classify grains which fit all of the criteria of a plutonic grain, yet did not have microcracks. Therefore it is uncertain as to the true origin of some grains I have classified as volcanic, however their presence in the VLB has been explained.

My inexperience with CL has also been a factor in this project. My technique has developed and improved over the course of the analysis; consequently I revisited some of the slides I classified earlier on. Inexperience with the SEM is also apparent, as the images obtained during the first session are not as good as those from the second and third session. This may also have had an effect on the final results. However we were able to

build on the technique from Bernet & Bassett (2005) with the addition of the use of Backscatter Electron Images to initially identify quartz grains for analysis. The addition of this step saves time and is an easy way to ensure that only quartz grains are chosen for classification.

Conclusion

Bernet & Bassett's (2005) integrated SEM-CL and optical microscopy methodology proved successful in identifying likely source rock types for single detrital quartz grains, as well as for the identification of remnant silica cements, which is indicative of sediment recycling. Grains that show silica cement are derived from the Beacon Supergroup, which originated primarily from the Granite harbour intrusives. CL imaging is the best way to do this, as the silica cements are often not distinguishable from the original quartz grain under an optical microscope.

CL analysis has also been used to identify sediment source areas, as single grains can be matched with their likely source in the Transantarctic Mountains. Plutonic grains are primarily derived from the granitic Granite Harbour intrusives, metamorphic grains are derived from the metasedimentary Koettlitz group and volcanic grains from porphyritic rhyolite clasts in conglomerates within the Beacon Supergroup.

Data from projects such as this can be used to piece together the glacial and tectonic history of the region in order to gain a better understanding of the geological and climatological processes that have shaped the landscape over time as variations in tectonics and climate are reflected in sediments deposited in the Victoria Land Basin.

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